THE DESIGN, CONSTRUCTION AND VALIDATION OF A NEW ASSISTIVE WALKING DEVICE FOR A CHILD WITH CEREBRAL PALSY

An Undergraduate Honors Thesis

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ABSTRACT

Cerebral palsy is a neuromuscular disorder that affects movement and posture. It is characterized by poor muscle tone and posture, spasticity, unsteady gait, limited mobility, speech impairments, and a forward displaced center of gravity. A child with cerebral palsy experiences certain impairments towards normal function and development, making typically routine daily functions such as eating, walking and writing a challenge. Perhaps the most prominent challenge for children with cerebral palsy is walking. Children with cerebral palsy use commercially available assistive walking devices to have some mobility and independence, but these devices are bulky, making it hard for the child to get close to his or her school work and friends. These devices are also not beneficial for every child because they may not provide sufficient body weight support which can result in a poor gait pattern and improper stance while the child is in the walker. The purpose of this research is to design, build and validate the effectiveness of a more efficient assistive walking device designed to help a specific six year old child with cerebral palsy interact with his peers and his environment.

In this study, the device that the specific child was previously using was analyzed using mechanical and biomechanical engineering principles to show desirable aspects of and areas that are lacking in designs that are currently commercially available. Video analysis and gait analysis were used to show the effective gait pattern of the child while using this assistive walking device. This analysis showed that the child was walking in crouch gait with hyperextension in his hips while using his current walker. His daily activities and functional capabilities were

analyzed in collaboration with the Occupational Therapy Department at the Ohio State University. This analysis showed that the child was unable to play with his friends, pull up to a table, or get close enough to use a computer while in his current assistive walking device. The results of these analyses helped show where improvements needed to be made in the new design. The improvements that are needed include a more open, smaller and light weight frame, a portable work surface, and additional body weight support. The new design was created using these needed improvements as a guide. The construction and final analysis of this new assistive walking device was performed during the spring of 2008 in order to validate the anticipated effectiveness of the improvements.

ACKNOWLEDGMENTS

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CHAPTER 1

INTRODUCTION

Cerebral palsy (CP) is a neuromuscular disorder that affects movement and posture. It is the most common cause ofphysical disability in childhood (Colver*et al.*, 2000) with a reasonable estimate of 700,000 children and adults up to age 50 are living with CP in the United States (ucpresearch, 2008). The rate of incidence of CP has increased in recent years, parallelingsubstantial increases in survival rates inlowest birth-weight groups and an increase in rate of survival in infants born prematurely (Stanley FJ, Watson, 1992;Colver*et al.*, 2000). Cerebral palsy is characterized by, but not limited to, poor muscle tone and posture, spasticity (a tightness in muscles that is characterized by continuous and painful muscle spasms (NINDS, 2007a)), unsteady gait, limited mobility and speech impairments (NINDS, 2007b). CP has negative effects on cognitive, emotional and social development because it often limits the ability to move in an efficient manner(Damian, 2006). Due to this, CP interferes with the ability of an individual to carry out daily activitiessuch as eating, walking, writing, and using a computer(Bjornson *et al.*, 2007). Children with CP often experience difficulty controlling muscle movement, and, therefore, tasks that may seem simple to most people become an overwhelming challenge to them. Walking, and even standing, can be a major problem for people with this disability because of asymmetrical distribution of muscle tone, poor ability to shift weight and a forward displacement of center of gravity(Thompson-Rangel *et al.* 1992).Approximately 25 percent of the people with cerebralpalsy identified by registries in France and the United Kingdomare unable to walk (even with assistance)(Kuban andLeviton, 1994). Many people with CP spend their lives confined to a wheelchair. It can be assumed that if a child is not walking by a certain age, he or she never will gain the ability to walk (Wu *et al.*, 2007). Although use of a wheelchair affords children with CP some mobility, access to social interactionremains limited and constant sitting is detrimental to physiological function and growth.

An assistive walking device, like the one in Figure 1, can be an extremely useful tool in helping a child to interact with others (Sussman and Aiona, 2004). Through exercise and proper posture the child's mind and body can be stimulated (Palisano, 2008). It is believed that children with CP should be as mobile as possible to try and improve performance in school related and normal childhood activities(Damian, 2006). This improvement is more likely to occur with instruction, practice, environmental modifications and assistive technology such as walkers(Palisano *et al.*, 2007). When the proper walker is used with the child, the hope is that he may gain some additional muscle tone and trained posture aligned with torso over hips over knees over feet (Thompson-Rangel *et al.* 1992).In addition to this, being mobile allows interaction at a level not elevated above other children while in a wheelchair.

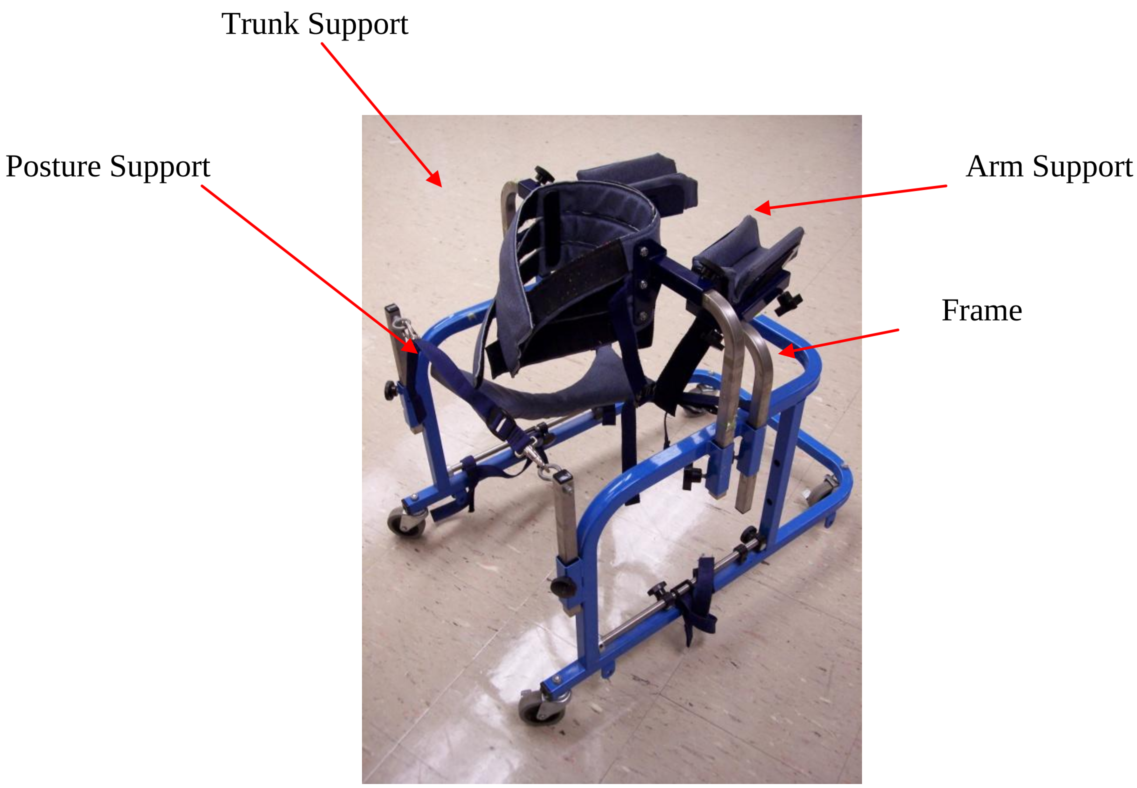

Figure 1: Assistive Walking Device.

The metal Frame connects the Arm Supports, Posture Support and Trunk Support. These supports allow the child to walk with assistance.

Figure 1 shows the current walking device that is used by children at the Nisonger Center Preschool at Ohio State. The arm supports on this device serve as a place to reinforce posture as well as support the child using the device if he or she does not have sufficient arm musculature or dexterity to use handles. The trunk support resists some anterior-posterior movement and supports the child in an upright position. The posture support allows the child to rest when tired, in addition to keeping the child from sinking below the walking device. In this walker, the posture support does not provide any vertical support. The frame holds some of the weight of the child and connects all of the supports. The frame moves forward on four casters.

Current walkers, like the one in Figure 1, provide a greater amount of mobility for children with CP than they would have without it, however certain drawbacks exist. Some walkers are bulky, have a complicated setup, cost over a thousand dollars and often don't provide sufficient support during movement, especially when the child using it cannot support his or her own body weight. These devices are not beneficial for every child because they may not provide sufficient body weight support, which may result in a poor gait pattern and an improperly aligned posture. Often, these devices have large frames that make it difficult for children to get close to tables, desks, computers or even their classmates and friends.

1.1 FOCUS OF THESIS

The purpose of this research is to create an assistive walker for a six year old boy who suffers from cerebral palsy. The goal for his assistive walker is to allow him to interact with his peers and his environment and help him walk without confining him to a huge metal frame that keeps him separate from his peers. This walker will provide more body weight support so that he can stand with better posture and walk with a more beneficial gait pattern (McNevin*et al*., 2000). It is hoped that the use of this walker will help him and similar children not only interact with their friends, family and classroom, but potentially gain muscle tone and confidence that will carry on through the rest of their lives.

1.2 SIGNIFICANCE OF RESEARCH

Cerebral palsy is the most common cause ofphysical disability in childhood(Colver*et al.*, 2000) and the rate of incidence of CP has been increasing in recent years. Children with CP often experience difficulty controlling muscle movement, and, therefore, tasks that may seem simple to most people become an overwhelming challenge to them. Many people with CP spend their lives confined to a wheelchair. Although use of a wheelchair affords children with CP some mobility, access to social interactionremains limited and constant sitting is detrimental to physiological function and growth. Assistive walking devices provide the support needed to get some children with CP mobile. However, current assistive devices don't work for every child. The significance of this research is to create a process for enabling specific children's needs to be met by assistive walking devices so that they can experience to mobility that is so important to childhood.

1.3 OVERVIEW OF THESIS

Chapter one is comprised of background information on the research project. It also gives the focus and the significance of the research project. The next three chapters of this thesis outline the process that was taken to perform this research process.

Chapter two is an analysis of current assistive walking devices. The analyses for this chapter were completed in the summer of 2007. This is comprised of three sections. The first section of chapter two outlines different groups of current commercially available walking devices. This was research done to find out the different types of devices that are currently available for purchase. The pros and cons of each of the types were outlined in this process. The second section of chapter two is an outline of the advantages and weaknesses of the current assistive walking device in use at the Nisonger Center Preschool. The last section of chapter two is a center of mass analysis of the design discussed in the previous section. This is an analysis of the device to see where the center of mass is located and how much of an angle would be required to tip the device over. This quantifies the fact that the walker is over-engineered.

Chapter three is a functional analysis of the current assistive walking device being used at the Nisonger Center Preschool. The first section is an analysis of the child's daily activities while in the assistive walking device. This analysis was done by the OT department at OSU to show the limitations and benefits of day-to-day functions in the walker. This part of the thesis was performed in collaboration with Jane Case-Smith and Lindy Tomawis of the Occupational Therapy Department at OSU during the spring and summer of 2007. The second section of chapter three is a description of the gait analysis that way performed with the child using his current assistive walking device. This analysis was performed in the gait lab at OSU in the autumn of 2007.The last section of chapter three is a gait data analysis taken from a video of the child walking. This is a preliminary kinematic analysis of the gait of the child to see how he moves in his current walker. This was accomplished in the summer of 2007 through measuring angles on a still frame of a video taken of a gait cycle.

The fourth chapter outlines the design process. The first section of this chapter is comprised of suggested modifications to the current device to increase its efficiency. The priority of certain design aspects was analyzed for this section in order to create the three dimensional solid model of the device that is discussed in the last section of this chapter. This section outlines the new design of the assistive walking device that was completed for this project. The new walker will be constructed using the completed design. The last section of this chapter is comprised of a center of mass analysis of the new design that was outlined in the first two sections.

The fifth and final chapter of this thesis is a summary. The first section of the chapter reiterates the most important aspects of the project. The last section of the chapter is comprised of suggestions for future work with this project.

CHAPTER 2

ANALYSIS OF THE EXISTING DEVICES

2.1 ANALYSIS OF COMMERCIALLY AVAILABLE DEVICES

A few main types of commercially made walkers are currently available. These include: walkers that support the children from above, partially supporting their weight, walkers that are held behind the child and walkers that are held in front of the child, and other types of walkers. These devices offer a range of options and support during standing and walking. Each is discussed below.

Figure 2: Pediatric Lite Gait® Mobility Frames (Sammons Preston, 2008)

This device's crane-like design allows the child to be partially or fully body weight supported while walking. In this figure the device is being used with a treadmill, but the wheels on the base of the device allow it to be used to give the child mobility around a classroom. The bulky nature of this devices design does not allow the child to get close to anything.

Walkers that support the child from above, like the one shown in Figure 2, partially bear the child's weight as he stands and moves. The device has an adjustable height and allows the child to grow without replacing the device. Arm supports are available for additional stability. This device is appropriate for a child who cannot stand independently. Despite its flexibility and support of the child, this type of device has a few flaws. It has a large frame that limits how close the child can get to a table or an activity. In addition, the device does not prevent leaning forward or backward so that the child may not stand in an upright position with head, shoulders, hips and feet well-aligned.

Figure 3: Rifton Pacer Gait Trainer (Rifton, 2008)

In this figure, the child is using an anterior assistive walking device. The device supports a child who has a forward displaced center of gravity. This device however does not correct for this displaced center of gravity as can be seen in the figure.

Figure 4: Rifton Pacer Gait Trainer (Rifton, 2008)

This figure shows a posterior assistive walking device. The child in this figure does not require a lot of body weight support. The posterior assistive walking device allows for some correction of a forward displaced center of gravity. The child in this figure is standing with good alignment.

Anterior and Posterior supportdevices often provide less support than others and the child must be able to support all or most of his weight to use. The weight-bearing promotes bone growth and muscle development, but these devices do not always promote good alignment and functional gait patterns. Walkers that are anterior support walker, or ones that are held in front of the child,like the one in Figure 3, may result in leaning forward into the walker and walking on toes. Walkers that are posterior, like the one in Figure 4, tend to promote a more upright position with the child more likely to bring his weight over his heels. Although the posterior walker is preferred for most children with cerebral palsy because it forces children with a forward displaced center of gravity to stand upright, it does not work for children who require some body weight support or who have lower extremity contractures. Some of these walkers provide optional forearm supports for children with weak or unreliable grasp. They sometimes have ankle straps that can reduce the stride length.

The walker currently in the preschool, shown in Figure 1, fits into the "other" category. It doesn't have support from above, in the front or in the back. The walker currently in the preschool attempts to support the child with torso support, arm support, and a seat that are all connected to a large frame.

2.2 ANALYSIS OF CURRENT WALKER AT THE PRESCHOOL

Figure 5: The Existing Walker at the Nisonger Preschool.

Although the existing walker allows for some mobility and has certain specific advantages, it is very bulky and large and doesn't provide sufficient support.

The current device that is used by children with mobility disorders at the Nisonger Preschool is pictured in Figure 5. Using this device allows children there to be able to have some mobility and independence. There are a few features of this device that are very beneficial towards these goals.

Arm platforms support child’s upper body without him/her having to have the ability to grip the support. Thesearm supports are adjustable in the vertical direction for comfort and posture purposes; in addition be able to have a more compact device for transport and storage.

Figure 6: The Seat of the Walker.

This figure shows the seat portion of the current walker. The seat is made out of fabric and padding that is hung from the frame. This seat allows the child to bend his knees and sink into a seated position when he is tired. The seat does not provide any support while the child is walking or standing.

A low hanging support strap that can be seen in Figure 6 allows the child to sit when he or she is tired. This strap does not provide body weight support during walking in order to force the child to gain strength by supporting his or her own weight. However, if the weight bearing forces become too tiring, they have the option of taking a break to sit in the walker without being taken out of the device.

Figure 7: Adjustability of the Armrests.

This figure shows the adjustability of the current device. The frame itself is not adjustable, but the arms, seat and torso supports are. There are two separate telescoping poles in for the arm rests. The positions are selected using a setscrew.

The height of the seat, the arm supports and trunk support are adjustable. The telescoping tubing that is used for this adjustment can be seen in Figure 7. The positions of the adjustable parts are set using set screws. The ability to adjust allows for the device to be customized fitting each individual child that needs to use the device. This is also a nice aspect for storage and transportation, as these parts can either be compacted or fully removed.

The entire device is not lightweight, but it is robust. The frame is made out of steel tubing which allows it to withstand sizable loads without failing. The frame is stable even if the child leans in different directions. The tubular cross section also allows for the design to have a lighter frame. The frame is stable even if the child leans in different directions.

Figure 8: The Torso Support.

This figure depicts the torso support. Velcro is used to fasten the padded pieces of fabric around the torso of the child.

Strapping around the torso, seen in Figure 8, provides posture reinforcement for the child while using the walker. This is beneficial for the child even if he or she is just standing in the walker. The strapping is easily adjusted for any child with the use of Velcro. It also prevents the child from leaning too far forward or too far backward. The trunk support that is created by using these straps in this device appears greater than in some commercial walker designs.

The current device that is used by children with mobility disorders at the Nisonger Preschool also has some limitations. The limitations of this device prevent it from being effective for every child affected by cerebral palsy. These disadvantages of the design highlight some areas that can be improved upon in a new assistive walking device.

The torso support shown in Figure 8 doesn’t prevent slumping in the seat. It does not give the child any body weight support and therefore when he is too tired to stand, he bends his knees and sinks downward. This forces him to raise his arms to an uncomfortable position above his head.The torso support also places pressure under the child's armpits when he leans forward.

The child's foot movement is not adequately confined, allowing him to lean forward and promoting hip hyperextension. His stride length then becomes too large for him to be able to effectively recover and pick his leg up to begin another step. The result is that the child often ends up with both of his legs fully behind his torso pushing on the ground with his toes.

The frame is very cumbersome and potentially over-engineered. This over-engineering would make the frame very robust and restraint to tipping. The angles at which this walker would tip over are most likely too large to ever have the child encounter.Additionally, because of the size of the frame, the child cannot get close to a table, a computer or his peers. This limits the child's social and environmental interaction.

The height of device is becoming too smallfor the child and will not adjust further as he grows. This means that soon, he will no longer be able to use the device. It would be beneficial if the walking device had a few more inches of adjustability so that a new onewould not need to be purchased.

The device is not user-friendly to the adult who is positioning the child into the device. For instance, the torso support strapping system has four separate straps that must be tightened while supporting the child in the center of the walker. Additionally, because the arm rests and the torso support all adjust independently from each other, getting to the desired height is a complex and not always accurate process.

The child uses his arms to help him gain momentum in the forward direction. When he uses arm support to propel himself forward his arms come out of arm restraints. His arms cross in front of him. The arm restraints either need to better strap in his arms or have to ability to move with the child's arms to the new position

The walker in Figure 5 has a very large and obtrusive frame with many straps for the teacher to fasten while putting the child in the walker. In addition, this walker doesn't prevent the child's center of gravity from falling forward. Due to this, this walker does not hold the child in a desired posture for proper bone growth or allow him to interact with his environment effectively, like a normal school-aged child. The design could be improved by providing better support for the child in order to create desired movement, partial unweighting improves gait efficiency (McNevin*et al*., 2000), and also by streamlining the frame of the device.

Figure 9: The Child Using a Computer.

This figure shows the child trying to use a computer at school. He is unable to get close enough to the screen to press the blue button without assistance from the teacher.

An example of the child having trouble performing daily classroom activities can be seen in Figure 9. In this figure, the child's bulky walker is making it difficult for him to pull up to the computer. He is reaching very far to press the blue button, but needs the assistance of his teacher to reach it.

In conclusion, from this analysis it can be seen that although the current walker allows the child to have some mobility and independence, a new design is needed for the child because of the current design's large frame and inadequate body weight support. The new design will try to correct some of the limitations of the current device. The most important characteristics that need to be improved upon are the large cumbersome frame, the lack of body weight support and the insufficient arm rests.

2.3 MECHANICAL ANALYSIS OF CURRENT WALKING DEVICE

The current walker that is used in the preschool is very bulky and believed to be over-engineered. The total center of mass was calculated from the individual parts of the walker to determine at what angle the walker would tip over if it were to be tilted on a hill. This angle is to show the excessive measures that were taken in the design process to ensure the stability of the walking device. The center of mass can be thought of as the point on a body where the mass of that body acts as a force when gravity is applied. When the force from the center of mass is no longer between the forces from its supports, the walker will topple over.

The equation to find the center of mass for a particular view of the walker is shown below. These equations were used to find the center of mass for the side view as well as the front view of the walker.

$$COM_x = \frac{1}{m_{total}} \sum_i m_i x_i \tag{1}$$

$$COM_y = \frac{1}{m_{total}} \sum_i m_i y_i \tag{2}$$

$$m_i = \rho \forall_i = \rho \pi r^2 l_i \tag{3}$$

$$COM_x = \frac{1}{\rho \pi r^2 l_{total}} \sum_i \rho \pi r^2 l_i x_i = \frac{1}{l_{total}} \sum_i l_i x_i \tag{4}$$

$$COM_y = \frac{1}{\rho \pi r^2 l_{total}} \sum_i \rho \pi r^2 l_i y_i = \frac{1}{l_{total}} \sum_i l_i y_i \tag{5}$$

where

COM_x = center of mass in the x direction
COM_y = center of mass in the y direction
m = mass
l = length
$\forall$ = volume
ρ = density
i = part of frame
y = centroid in the y direction
x = centroid in the x direction

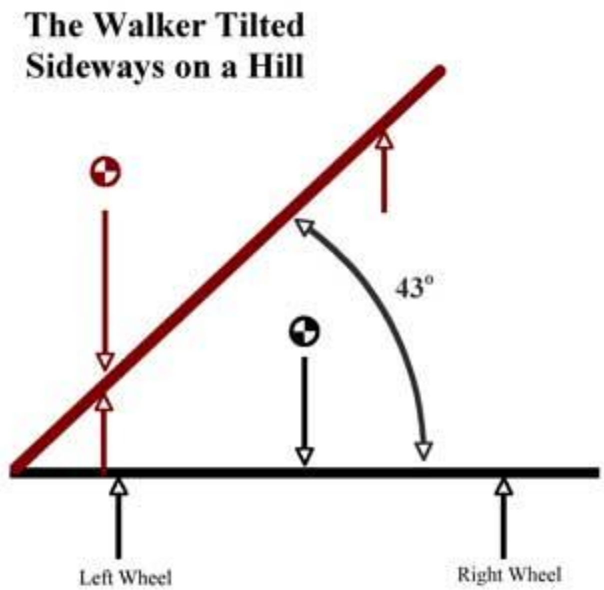

Figure 10: The Center of Mass Analysis Front View of the Walker.

The walker will fall over if it is on an incline such that the center of mass is no longer between the two supports. This occurs at an angle of 43 degrees when the walker is titled from side to side on a hill.

The simplified view of the walker depicted in Figure 10 shows the analysis that was done for the front view of the walker. In this figure, the right front side of the walker is tilted up a hill. The simplified view of the walker was tilted tracing the path that the wheels and center of mass would take with a compass to find out where the load from the center of mass crossed past the support from the wheel in the x axis. In Figure 10, the walker is tilted to 43 degrees from side to side before the walker falls over. A similar analysis was performed for the side view of the walker. In this case the walker was tilted both uphill and downhill. The walker tipped over when tilted to 70 degrees downhill and 67 degrees uphill.Values for all of the different segments can be found in the Appendix.

CHAPTER 3

EXISTING WALKER FUNCTIONAL ANALYSIS

3.1 DAY-TO-DAY ACTIVITIES

The following is an analysis performed by Jane Case-Smith and Lindy Tomawis of the Occupational Therapy Department at OSU.

Overall profile

For purposes of decision making on walker design and construction, we evaluated passive range of motion, strength, muscle tone, and postural alignment. We also assessed the child's functional performance in his current walker, through observation of his gait on carpet and smooth surfaces and observation of his posture during stance at the computer, using an Intellikeys program.

The child is six years old and is small for his age. He has cerebral palsy with moderate to severe spastic quadriplegia. Currently he is enrolled in a special needs preschool at the Nisonger Center and will enter kindergarten in South-Western City Schools in autumn. His family plans for him to attend the Nisonger Center Preschool summer program.

The child is generally happy, smiling frequently. He is attentive to speech and instructions, but it is not clear how much language he understands because responding is difficult. He appears to understand most of what is said to him and follows commands when the directive is physically possible for him. His expressive language is quite limited because his speech is severely dysarthric. He is unable to articulate most consonants and his speech is breathy, indicating that he has shallow breathing given the lack of trunk muscle tone and abdominal support to the diaphragm. The child has an augmentative communication device but he is not currently using it. Augmentative communication may be helpful to him in the future and may be a device that he can access when standing. It was observed that his speech increased when he was standing in his walker and the position of standing with his trunk in full extension may be optimal for speech.

Performance components for standing

Passive range of motion was measured with the child lying supine on the mat. Although these measures are generally made by the physical therapist, they were not present in the preschool evaluation (which focuses on functional skills). We made observations without use of a goniometer to determine if range of motion limitations needed to be a consideration in designing the walker.

Hip Range of Motion

Figure 11: Rear View of Stance in the Current Walker.

In this figure, the child is standing in his current walking device while using a computer. His hips are abducted and his feet are turned out in plantarflexion.

The child lies in hip abduction and external rotation. He also has some external rotation in stance. Internal rotation is limited bilaterally at the hips, but appears to be functional for stance. He has full hip extension. Both of these are illustrated in Figure 11 as well as the fact that his feet are turned out in slight plantar flexion.

Knee Range of Motion

Knee extension is full with hips extended, and due to hamstring tightness, it is significantly limited with hip flexed. This tightness does not affect stance, and would not affect step forward. It would prohibit long leg sitting.

Ankle Range of Motion

The child has severe spasticity in his ankles. Passive range of motion in dorsi flexion is limited by 20 to 30 degrees (he cannot get to neutral). To get to the -20º, we had to work through significant spasticity (resistance). Therefore, in stance, at present, the child cannot get completely flat footed. With his body weight over his heels, he can get to about -20º dorsiflexion, i.e., he is standing with plantar flexion. His occupational therapist stated that the family was working on obtaining ankle orthoses, but it was not clear when they will accomplish this.

Strength

The child has poor to fair strength throughout his body. He is particularly weak in his trunk and legs. His arms and hands move primarily is a flexion synergy (moving into elbow flexion) with limited shoulder flexion (he cannot raise his arms above his head) and limited shoulder external rotation and forearm supination. His legs move into extension using spastic muscle tone and he has poor or less than fair hip flexion to step. Therefore stepping is difficult, without full range, and only a few steps are possible without resting (This is his current status).

Muscle tone

The child has classic spasticity in arms and legs. His trunk and neck have low muscle tone; making sustained upright posture impossible. He can hold his head upright for several minutes and neck stability appears to be better in standing than sitting. He does not sit independently. Spasticity and underlying low muscle tone and weakness have created tightness in his shoulders, forearm rotation, hips, and ankles.

Functional skills related to using a walker

The child's current walker provides an adjustable seat with a small base that fits between his legs. Three chest straps hold his trunk upright. He also has arm supports that are cushioned trays that his arms fit into. In his current walker, the child can stand upright with hips over feet but he tends to lean into the walker with his center of gravity in front of his feet. He pushes the walker forward pushing his legs into extension. When he is positioned into upright stance (hips over feet), his legs are in some abduction and external rotation with feet turned out in slight plantar flexion.

His gait in the walker is very slow on carpet and is only slightly faster on linoleum. Most steps are pushing the walker with feet behind hips and weight forward. The arm rests seem to be helpful for forearm support, but his arms frequently fall out. He stiffens his arms in flexion to gain overflow and stiffening in his trunk to initiate walking.

Figure 12: Sagittal Plane of Stance in Walker.

In this figure, the child is using a computer while in his assistive walking device. Due to lack of body weight support, his knees are in flexion.

Standing in the walker is beneficial for the child. Weight bearing on his feet helps to reduce the muscle tone in his ankles, strengthen his legs and trunk and improve circulation. It is also helpful for bone and joint development. We observed the child standing in his walker while working at the computer. The front piece on his current walker makes it difficult to position him close to the computer and to access the keyboard. In standing, his alignment ranges from poor to fair. He tires easily and must be reminded to stand upright. He can stand with hips over feet, but he frequently leans forward or flexes his knees so that he is no longer standing. An example of this can be seen in Figure 12. Here it can be seen that the child needs more bodyweight support in order to correct his constant knee flexion. It would be beneficial to have chest straps and a seat that helps him maintain his hips over his feet and maintain his center of gravity over his feet. A better gait patterns for him would be to learn to shift his weight to the side and move forward with a lateral weight shift. A walker design should allow for lateral weight shift.

The child stood at the computer for about 20 minutes. This is probably the longest he is able to stand in a device. He used his hands to hit a switch to activate the computer program, but the switch had to be positioned near to his hand and he needed frequent prompting.

Assessment/Recommendations

The child can stand in a walker but needs assistance to maintain his alignment. Issues in maintaining upright alignment are that his hips are abducted and externally rotated and his ankles do not have full dorsiflexion range.

Seating and chest straps should help him keep his weight over his feet, if not slightly behind his feet to counter his tendency to lean forward. Strapping should allow for lateral weight shifts.

The child has difficulty maintaining his arms in the arm supports. The arms supports appear to be helpful to him in maintaining his trunk upright and in supporting his weight. A more flexible arm support that would allow for minimal movement when he brings his arms forward may be helpful. In addition, a more secure strapping system is needed, as his arms tend to break free and fall between the arm supports and deter upright posture. It may also be beneficial to have arm supports that swing away so that he could move up to a table and use his arms on the table surface.

Standing in the walker is probably a more important goal than walking, at least at present, due to the aforementioned limitations in strength, muscle tone, and ROM. This goal reinforces building a walker that will allow him to move up to a table or computer desk and use his hands on the surface. Without the bars in front, other children and adults can also approach him easier.

The wheels of his current walker keep him from moving quickly forward by providing some resistance when he pushes his weight forward. This concept seems important as a method to promote his shift of weight backwards and upright stance.

Standing in the walker will be important to interacting with peers, to speech, and to working on table surfaces. Neck control and trunk control seem to be optimal in the walker and better than in sitting.

3.2 GAIT ANALYSIS

In the autumn of 2007, we analyzed the child's gait while he was in both the current walking device at the Nisonger Center Preschool and his personal gait trainer. We did this to get a more accurate picture and not just an approximation of how the child walks in these devices. Gait analysis accumulates data for comparison with a normal gait cycle allowingfor the characterizationof the child's movements.

Figure 13: The Gait Laboratory.

This figure shows the gait laboratory that was used for the gait analysis. It is a converted gymnasium. The IR cameras are emitting orange light. There are two force plates in the black portion of the floor.

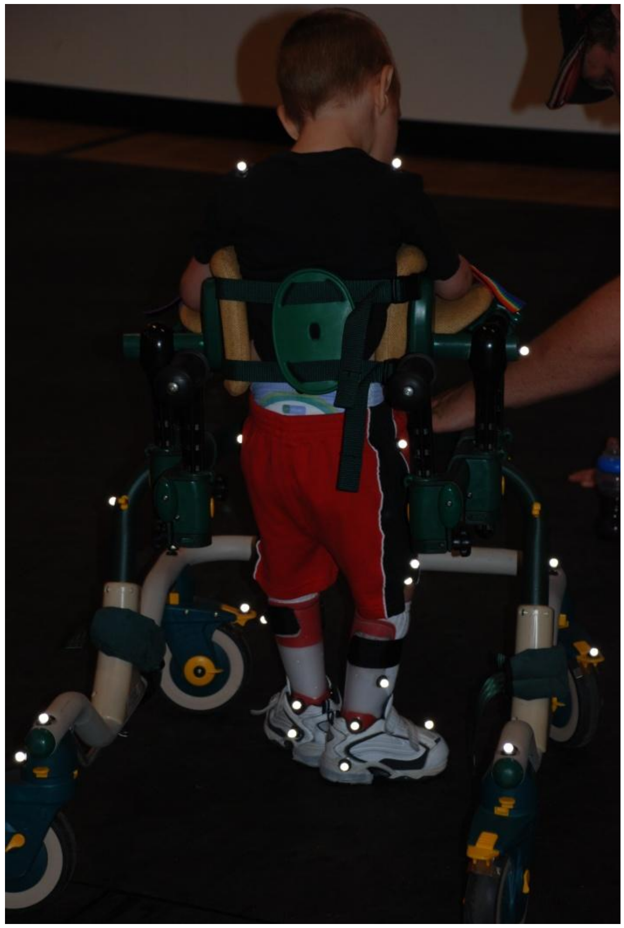

Figure 14: Markers for the Gait Lab Analysis.

This figure shows the child in his gait trainer at the gait laboratory. The white dots are the passive optical markers that illuminated with the flash of the camera.

A gait lab analysis can be used to show the kinematics and kinetics of how someone moves or more specifically, walks. It consists of markers to capture motion and force plates to show weight distribution.Motion capture is used by biomechanists to characterize kinematic motion of parts of the body. There are various types of motion capture. This experiment used a passive optical marker system which reflected the IR lightfrom multiple IR cameras.Multiple IR cameras like the ones in Figure 13 were set up in the gait laboratory. The collection of multiple angles of 2D data allowed for the conversion of it to 3D data.Reflective markers like the ones that can be seen on the child in Figure 14 were used to show where the child limbs were over space and time. The data can be manipulated to get angles between joints.

Figure 14 shows the child in his personal gait trainer. The white spots show where makers were placed on his body and the walker. The markers were placed on the child with on one each of his shoulders, one on each of his hips, one on his sacrum, one on each of his mid thighs (left higher than right), one on each knee, one on each mid calf (left higher than right), one on each ankle, one on the back of each heel, one on each of his second metatarsals. Markers were also placed on the walker so that the forces for the child and from the wheels of the walker could be discerned. These markers were placed with one on each of the top and bottom corners and one of each of the wheel brakes.

Figure 13 shows the gait lab that was used for the analysis. Multiple IR cameras were used to collect the data. Two force plates are embedded in the floor. Force plates imbedded in the floor allow for simultaneous collection of ground reaction forces. Ground reaction forces are the forces that the ground places on the body in response to the forces that the person exerts on the ground. Using inverse dynamics, knowing these forces allows for the calculation of the torques acting around each joint.

The first test was for initiation of walking. The child began with one foot on each force plate. He took a few steps. This test was meant to show forces for push off. For this test, the walker was allowed make contact with the force plates.

The second test was for standing. The child began with one foot on each force plate. He began in the seated position and then was asked to stand in a complete weight bearing position. This was to show his ground reaction forces and posture while standing.

The last test was for walking. The child began with both feet on force plate. For this test, the walker was not allowed to make contact with force plates. At the start position the front wheels were already off of the force plate and the back wheels were straddling the force plate.

Figure 15: Poor Alignment in the Gait Trainer.

In this picture the child's legs are in poor alignment with the center of his body. Due to his uneven distribution of muscle tone, he tended to push the walker in circles when not guided.

Even though a complete analysis has not yet been performed with the data from the gait lab, some important observations were made. The child seemed to be walking in crouch gait in both his gait trainer and the assistive walking device from the Nisonger Center Preschool. He also seemed to be stronger on one side than the other making the device pull in circular arcs instead of going straight. Figure 15 shows the imbalance of his strength. In this instance his legs are both off to one side of the gait trainer and not underneath his torso. None of these positions are very beneficial to him walking in the walker. The child was very happy to be in the walker and chose to walk rather than stop even when he was visibly tired. The AFO’s he was wearing seemed to help him take more steps, but he tired very quickly.

3.3 VIDEO ANALYSIS

It is possible to use a simple video to roughly estimate a person's kinematics. In this analysis, stills from a video of the sagittal plane of the child walking were evaluated to find the angles of hip and knee flexion over a gait cycle. These flexion angles are graphed vs. percent gait cycle and compared to a normal gait pattern below.

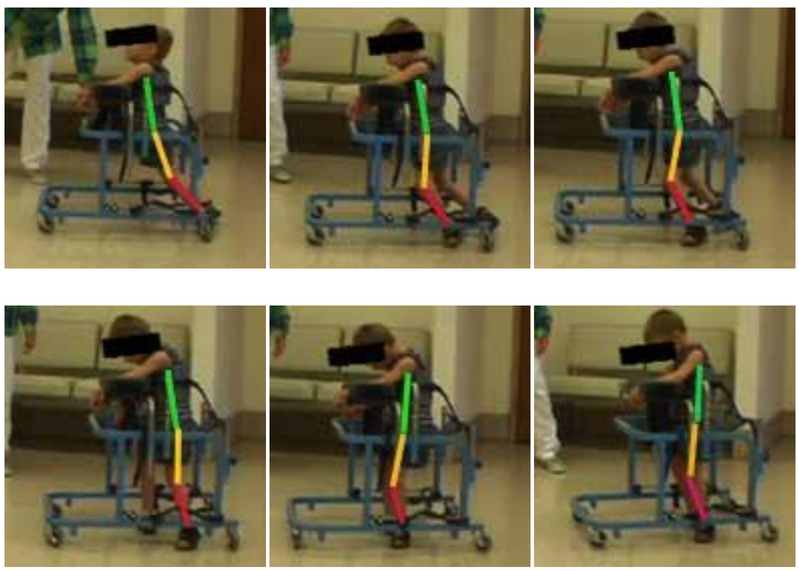

Figure 16: Stills for Gait Analysis.

These stills show the approximate vectors of the HAT (head, arms, torso) in green, the thigh in orange and the shank in red that are used to find the HAT angle, thigh angle and shank angle.

The stills that were selected and shown in Figure 16 were analyzed because they showed different points of interest during the video. The stills were taken from different points during swing and stance over the period of one step. The progression of these still photographs is from left to right for the top row and then across the bottom row in the same direction. The first two still photos show the leg beginning the swing phase. The swing and stance phases for the gait of this child were hard to distinguish as he put his foot down on the floor to push off more than once.

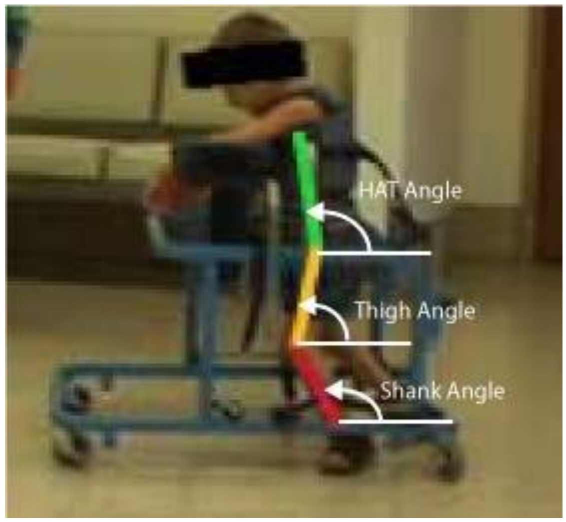

Figure 17: Angles from the Horizontal.

This still shows the shank, thigh and HAT angles. These angles are used to find the knee and hip flexion angles.

The equations to find hip and knee flexion angles are as follows.

$$\text{Knee Flexion Angle} = \text{Thigh Angle} - \text{Shank Angle} \tag{6}$$

$$\text{Hip Flexion Angle} = \text{Thigh Angle} - \text{HAT Angle} \tag{7}$$

In Figure 17, the vectors for the HAT, shank and thigh were estimated roughly using each of these stills. Then, using the equations 6-7 for knee and hip flexion angle which are shown above, and the convention shown in Figure 17 to physically measure shank, thigh and HAT angles from the horizontal, the knee flexion and hip flexion for each discrete point of the gait cycle were calculated.

The angles of hip and knee flexion were plotted over the percentage of the gait cycle so that they could be compared to normal gait data. This normal gait data was taken from an actual gait laboratory experiment so the curves are much smoother than the discrete estimates taken from the video gait analysis. These graphs show how the support in his current walking device allow him to move compared to how a normal person, pointing out where modifications of the design and its support need to be implemented.

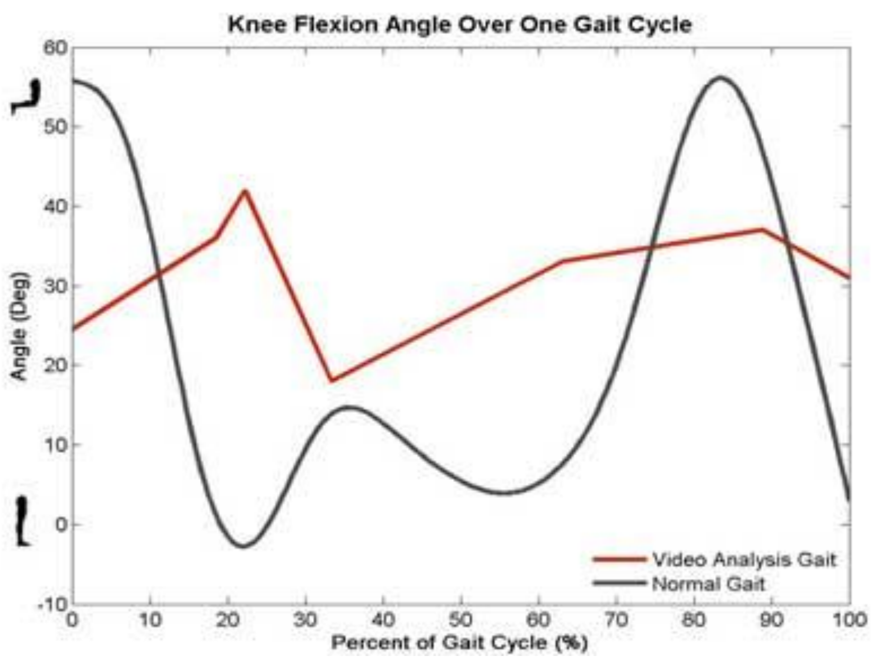

Figure 18: Knee Flexion as a Function of Percent Gait Cycle.

The curve of the child's knee flexion angle, shown in red, follows roughly with the curve of the normal gait data, shown in grey.

Figure 18 shows the knee flexion over the percent gait cycle. The smooth grey line represents normal walking. The red line represents the gait of the child. This graphs shows knee flexion ranging from -10 degrees of flexion to 60 degrees of flexion. The normal knee flexion ranges from nearly sixty degrees to just below zero. The child's knee flexion remains between the angles of 20 and 40 degrees. The overall range of the child's knee flexion angle was less than that of normal gait data. The knee flexion data for the child suggests that because the child is in constant knee flexion throughout the gait cycle, he is in crouch gait while using the walker. Crouch gait is defined as a tightness of the hamstrings which causes difficulty for a rapidly growingchild to stand up straight, and therefore forcing the child to walk with the knees bent (Ip, 2008). This is a counterproductive stance to be in while walking. Therefore, the data suggest that the child would benefit from more body weight support while walking.

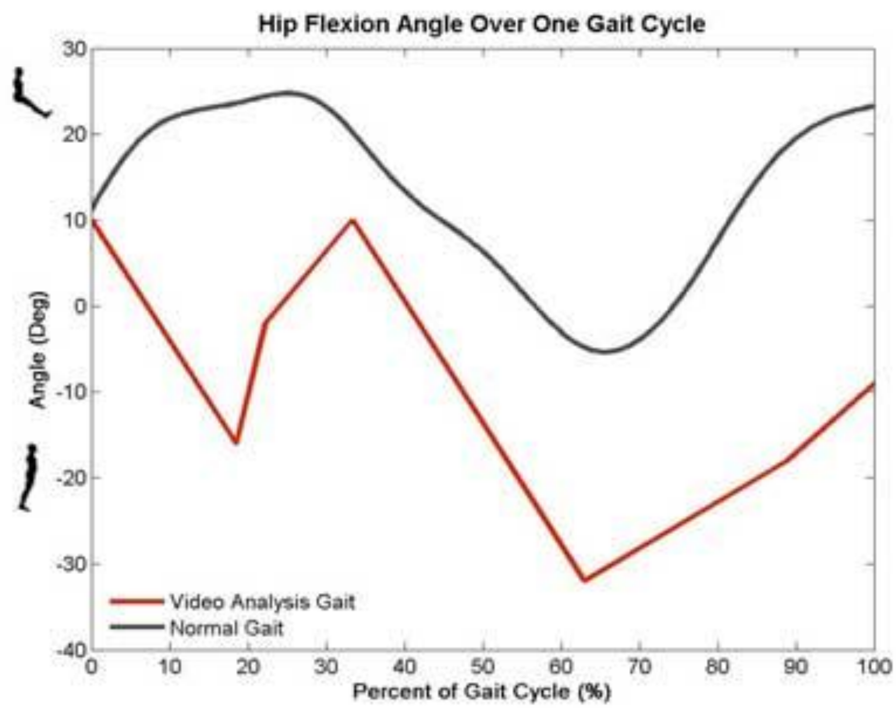

Figure 19: Hip Flexion as a Function of Percent Gait Cycle.

The curve of the child's hip flexion angle, shown in red, follows roughly with the curve of the normal gait data, shown in grey.

Figure 19 shows the hip flexion over the percent gait cycle. Similar to the knee flexion graph, the smooth grey line represents normal walking. The red line represents the gait of the child. This graphs shows hip flexion ranging from -40 degrees of flexion to 30 degrees of flexion. The child's hip flexion follows the same general path as the normal hip flexion plot. However, the child's hip flexion angle is smaller than normal and exhibits periods of extreme hyperextension. There is also a decrease in hip flexion angle early in the gait cycle that does not occur in normal hip flexion data. Hyperextension is what happens when the child's legs extend far behind his body. It is very difficult for the child to recover from this position and begin a new step.

CHAPTER 4

DESIGN OF NEW ASSISTIVE WALKING DEVICE

4.1 DESIGN MODIFICATIONS

After the preliminary analyses, the desired improvements to the device were categorized based on importance and implementation. These improvements were a smaller, lighter, and adjustable frame, increased bodyweight support, more flexible arm supports, and posture restraints. After these were identified, the brainstorming process began. In the brainstorming process, multiple design modifications were sketched for each of the needed improvements. The categories for these were adjustability, body support and posture and arm support. All of the sketches for the brainstorming process can be found in the Appendix.

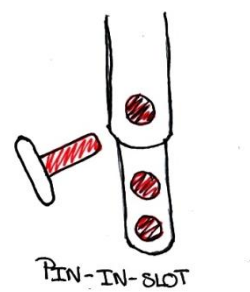

Figure 20: Adjustment Brainstorming

This figure shows a pin-in-slot type of method for adjustment. The pin is set into discrete holes in the tubing to allow the telescoping tubing to stop at various heights.

Adjustability in this application is important because it will allow the walker to help the child as he grows and will not limit its usefulness based on the size of the child. Adjustability for the frame could come in many forms. A scissor-like frame (as used in stretchers) allows the height to be changed by pivoting 2 bars around a fixed point. A rack and pinion adjusts the height by letting part of the frame travel vertically. This mechanism can be driven either by a motor or by hand. A pin-in-slot, compression ring clamp and a set screw were also considered as feasible options. These are all similar in design because they use telescoping tubes of various lengths to allow for the selection of different heights of the device. Figure 20 shows the brainstorming sketch of the pin-in-slot type of adjustment.

Initially it was desired that the child bare all or most of his body weight while upright in the walker. However, after the video analysis data was evaluated, the idea was modified. Due to this analysis it was determined that the child needs to be better supported while in the walker so that he can maintain a proper posture and benefit from a stance that is not in crouch gait. Therefore, partial body weight support will be a key feature in the new design. A harness would allow him to be supported in the vertical direction without obstructing his gait. A stationary seat would allow for both a place to rest and help support some of his weight.

Standing with proper alignment at the eye level of his peers is just as important as walking for the child. Restraints at his knees would force him to stand properly without bending his knees which would prevent his from standing in crouch gait. A rigid trunk support like he currently has would hold his trunk from leaning anterior or posterior. Ankle straps would limit his gait so that he would not be allowed to end up in extreme hip hyperextension. A bungee cord pulling his shoulders upright would pull him into the correct alignment with his head over his shoulders over his torso. Additionally, it is possible that more body weight support would allow for better posture alignment while in the assistive walking device.

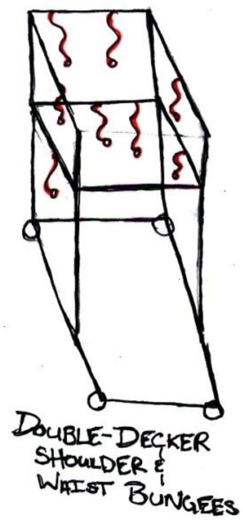

Figure 21: Support Attachment Brainstorming

This figure shows the double-decker method of support for a child using the walking device. A rock climbing harness would be attached to the bungee cords which are attached to the frame. This would allow for a flexible method of support.

Figure 21 shows the double-decker frame brainstorming idea. This idea would allow for partial body weight support of the child by using bungee cords to pull him upwards. It would also allow for the child's shoulders to be pulled backwards to counteract his forward displaced center of gravity.

Current arm support usually comes in the form of handles or arm trays like the ones used on the current walker at the Nisonger Center Preschool. These could be improved by allowing them to swivel and move with the child. Also slings could be used instead of rigid platforms. A single tray platform would allow the child to swing his arms inward and have them constantly supported during that motion.

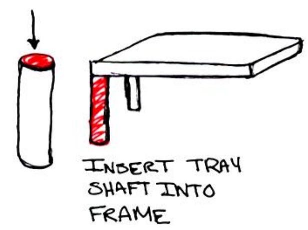

Figure 22: Tray Attachment Brainstorming

This figure shows one of the brainstorming methods for the tray attachment to the frame of the walker. In this figure the tray is attached to the frame by slipping the shaft on the tray into tubing on the frame of the walker.

The tray was decided on as the desired type of arm support early in the design process. This surface would not only support the child, but also allow him to play, eat and do schoolwork on his own portable surface. It was also desired that the tray could be removed so that the front of the frame of the walker would be left open. This would allow the child to pull up to a table, a computer of his friends. In order to meet both of these specifications methods of attaching the tray to the frame were brainstormed. Figure 22 shows one of the tray attachment ideas. In Figure 22, the tray is attached by the use of telescoping tubing.

The size and weight of the new frame need to be reduced in comparison to the size and weight of the frame of the walking device at the Nisonger Center Preschool. The weight of the frame is just as important as the size. The frames weight becomes a burden for the parents, teachers and therapists during transport from house to school as well as to therapy. Due to this, the frame will be made out of aluminum and not steel which will cut down on the weight. The frame size will be reduced as much as possible by cutting away excessive supports and curving it around the child's body in the new design. A curved frame will be streamlined without sacrificing the needed support and room for the completion of a step.

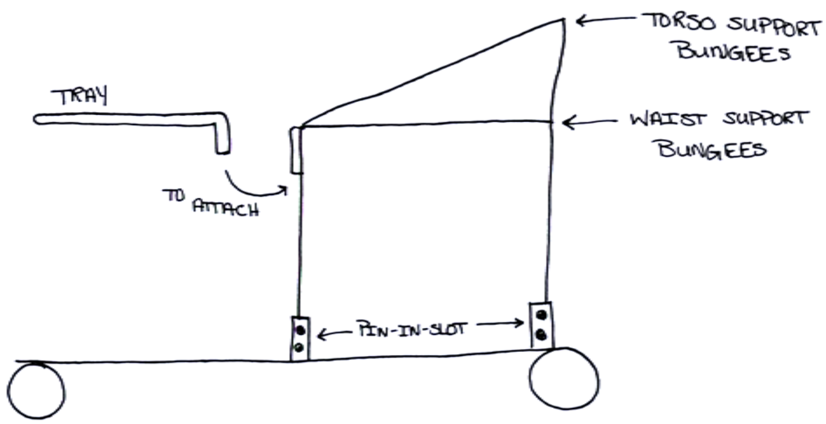

Figure 23: Brainstorming Sketch of Final Design Concept

This figure shows the complete final design concept. The chosen method for adjustment was the pin-in-slot method. The method chosen for the tray attachment was the vertical shaft telescoping in the tubing on the frame. The chosen support attachment was a tapered double-decker support with bungee cords.

A final concept from each category was chosen based on performance characteristics and their compatibility with the other initial brainstorming concepts. The selected brainstorming concepts were combined to form the design of the new assistive walking device. This design is shown in Figure 23. The design was then modified and the process reiterated until the model of the prototype was determined to be an improvement on the old device.

4.2 THE FINAL DESIGN

After the selected brainstorming concepts were combined to form the design of the new assistive walking device, solid modeling was used to specifically lay out parts and dimensions for the assembly of the new device. A lot of improvements were needed, but in order to simplify the final design only a small number of important improvements were selected to simplify the final design. The design was modified until the model of the prototype was deemed satisfactory. Some innovative components were used to finalize the design.

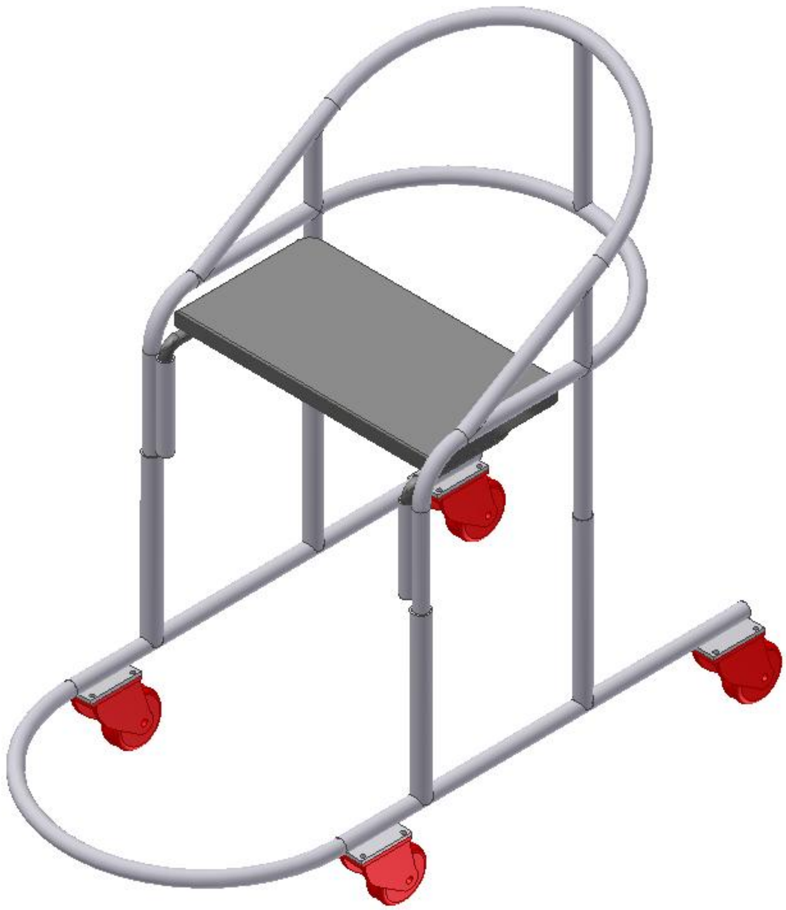

Figure 24: The Design of the New Assistive Walking Device

This is the final design of the new assistive walking device. The frame is 1/8th inch wall-thickness aluminum tubing. The tray is a polycarbonate sheet. The child will be supported in the frame just behind the tray using a child's rock climbing harness.

The frame was designed using circular aluminum tubing. This material is very light compared to the steel that was used to build the walking device at the Nisonger Center Preschool. The frame of the new device can be seen in Figure 24.

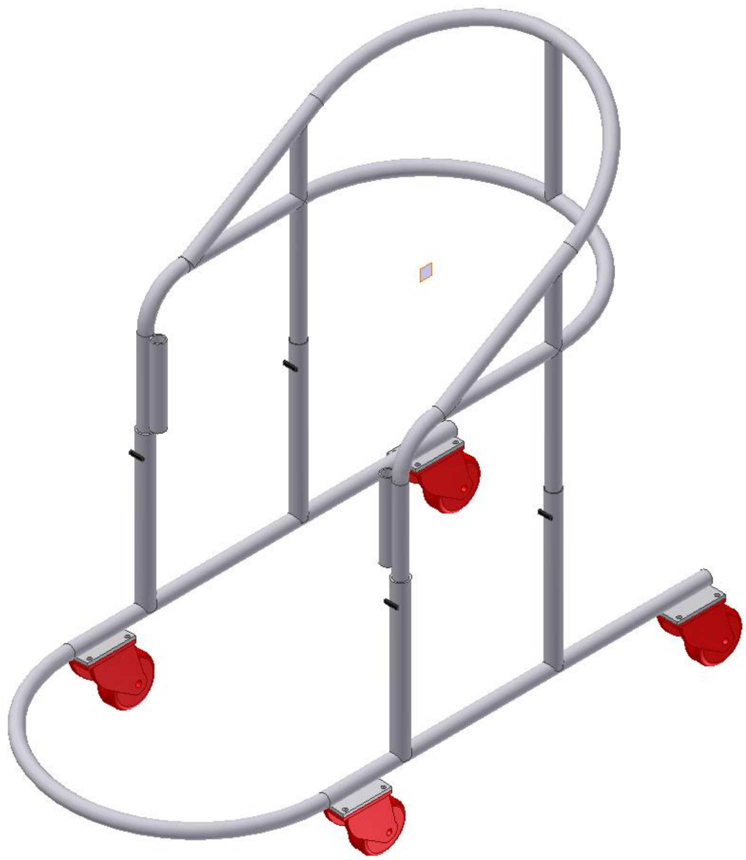

Figure 25: Walker Frame without Tray

The new walker design without the tray that is used for arm support is shown in this figure. The tray can easily be removed because it slides out of the telescoping tubes which are welded onto the sides of the frame. This allows him to not have a physical barrier in front of him when he wants to interact with his peers and environment.

In addition to the change in the frame material, some areas such as the upper front section of the walker, directly in front of the child was removed so that the child would not be obstructed from reaching tables, activities and his peers while in the walker. This can be seen in Figure 25, where the tray has been removed from the frame which can be easily done due to the telescoping aluminum tubing. Additionally, the frame was then curved around where he would stand to avoid material from extending in an obtrusive square shape. The length of the bottom of the frame was chosen in order to fit one complete stride and the heights and widths of the design were all based on anthropomorphic data.

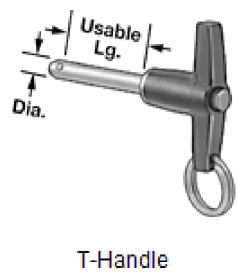

Figure 26: T-Handle Push Button Quick Release Pin (McMaster Carr, 2008)

This figure shows the spring loaded pin that is used to easily adjust the height of the walker. When the button on the end of the pin is pressed, the knobs on the end of the pin are drawn into it and the pin can be pulled out of the hole.

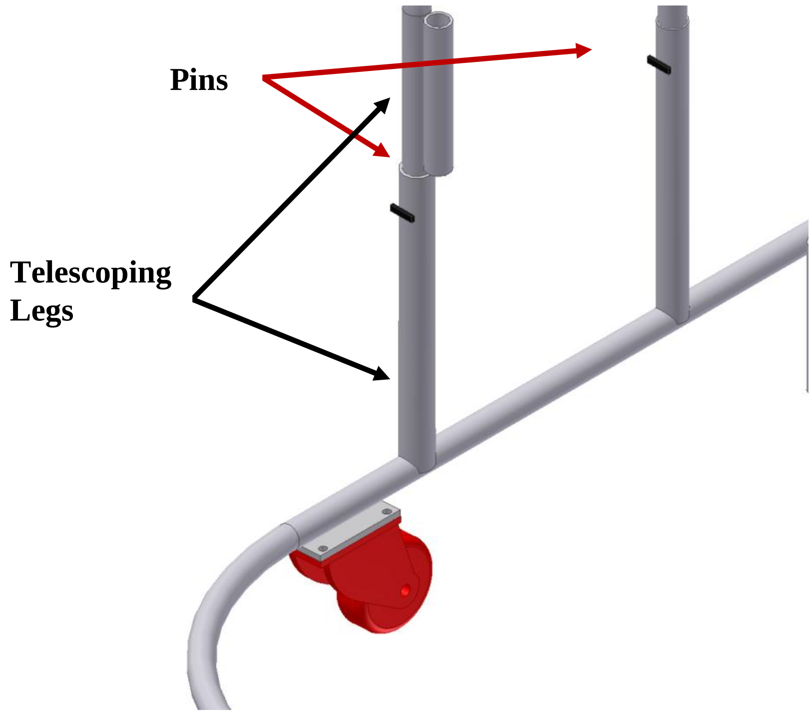

Figure 27: Telescoping Legs with Pins

This figure depicts the telescoping legs in the frame and the pins that allow for the selection of the height of the device.

The entire frame shown in Figure 25 is adjustable for various heights so that the child can grow and still benefit from using the assistive walking device. Telescoping tubes used in the four support legs allow the top and bottom of the frame move with respect to each other. Spring loaded pins hold the frame at discrete heights where there are holes drilled into the legs. The pins that were used are shown in Figure 26. A close up picture of the telescoping legs and the pins on the frame can be seen in Figure 27.

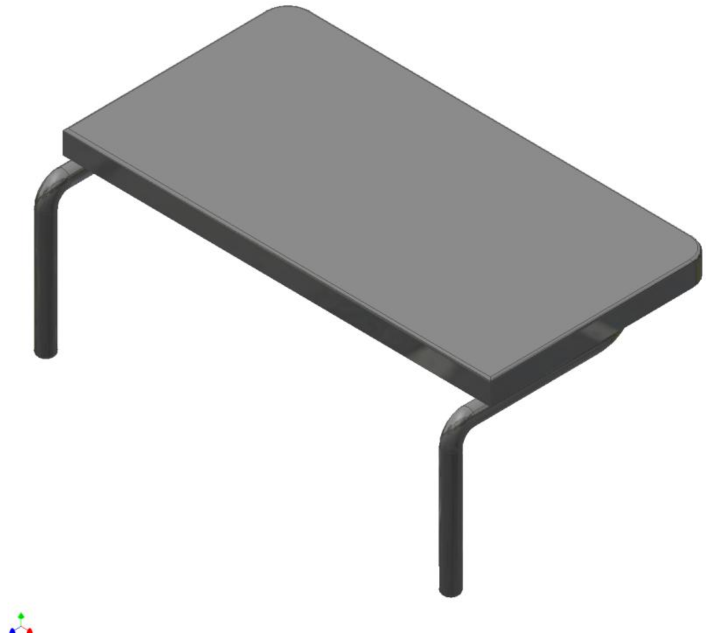

Figure 28: Tray

This figure shows the tray that is used to support the child's arms. The tray also creates a portable and personal work surface which can be used for schoolwork, crafts and eating off of.

Much like that of a tray on a high chair, a portable work surface would allow the child to have a space of his own for his work, but could be removed so that he could pull up to a computer or a table and do additional work. This is why a tray was chosen to provide arm support in the new design. This tray would also allow the child to move his arms inward while walking and still receive support. The tray can be seen in Figure 28. It can be completely removed from the device so that the front is open and the child can pull up close to a computer or classroom table.

Figure 29: Petzl OUISTITI Full body harness for children (PETZL, 2008)

This figure shows the child's rock climbing harness that will be used to support the child while he is in the walker. Bungee cords will be attached to the harness in order to connect it to the frame.

A child's harness for rock climbing would allow for lateral support at the waist and at the torso (from behind) when attached to the frame using bungee cords. The most important feature of the rock climbing harness is that it is specifically meant to comfortably support the child's body weight in the vertical direction. Therefore, by using a rock climbing harness the child could walk in without carrying the load of his full bodyweight. The rock climbing harness that will be used in the walker is shown in Figure 29. The lengths of the bungee cords connecting the harness to the frame would be adjusted to specifically meet the weight bearing needs of the child.

Figure 30: Swivel Showing Poly-Tech® Wheel (Hamilton Casters, 2008)

This figure shows the casters used for the project. The red plastic is a softer material than the white plastic inside. The wheels swivel using ball bearings.

The casters that were used in the design can be seen in Figure 30. They are made out of polyurethane on a polypropylene center for ease of rolling. The softer plastic material on the outside of the wheel is specifically designed for classroom and hospital settings. Ball bearings are used for ease of turning so that the wheels will be directed where the child wants to go without his having to put in a lot of extra effort. The casters have toe brakes so that the walking device can be still used when the child wants to participate in stationary activities such as using a computer.

Figure 31: The Completed Frame of the New Walker.

This figure shows the completed frame of the device. The top piece is all one solid structure that telescopes out of one solid bottom piece. These two sections both rest on four casters.

The assembled frame of the new walking device can be seen in Figure 31.The tubing for both the top and bottom segments was bend and welded to form the frame. The casters are bolted to the wheel plates, which are welded to the tubing of the frame. The spring-loaded pins are used to choose the height of the walking device. One pin can be seen in each of the four legs of the device. The tray is attached to the frame in this view and can be seen just below the horizontal tubing of the top section.

4.3 MECHANICAL ANALYSIS OF NEW WALKING DEVICE

For comparison with the current walker that is used in the preschool, a center of mass analysis was also done for the new walking device. This analysis is meant to validate that the new device is less cumbersome. The total center of mass was calculated from the individual parts of the walker to determine at what angle the walker would tip over if it were to be tilted on a hill. This angle is important in quantifying how over-engineered the walker is. The center of mass can be thought of as the point on a body where the mass of that body acts as a force when gravity is applied. This analysis was done the same way that the analysis in chapter 2, part 3 was done, using equations 1-5. When the force from the center of mass is no longer between the forces from its supports, the walker will topple over.

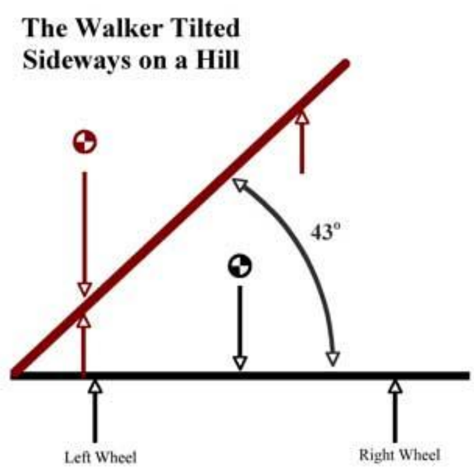

Figure 32: The Center of Mass Analysis Front View of the New Walker.

The walker will fall over if it is on an incline such that the center of mass is no longer between the two supports. This occurs at an angle of 43 degrees when the walker is titled from side to side on a hill.

The view in Figure 31 shows the analysis that was done for the front view of the walker. In this figure, the right front side of the walker is tilted up a hill. The walker is tilted to 43 degrees from side to side before the walker falls over. A similar analysis was performed for the side view of the walker. In this case the walker was tilted both uphill and downhill. The walker tipped over when tilted to 35 degrees downhill and 54 degrees uphill. The differences in these two angles is because the center of mass is not at the center of the device and therefore the device is more likely to tip over when tilted going down a hill.

These angles show that the new design has less stability at higher angles. The side to side tilt is the same as the original device. The downhill tilt has improved from 70 degrees which was excessive to 35 degrees of tilt. This is a much more reasonable number and is still sufficient in keeping the walker from tilting during use. The uphill tilt has also improved to 54 degrees from 67 degrees. The new angles show that the new walker is still really stable despite the modifications.

CHAPTER 5

FUTURE WORK AND SUMMARY

5.1 SUMMARY OF COMPLETED WORK

This undergraduate honors thesis and the new assistive walking is the culmination of four quarters of work. Although the project's initial goal of validating the new design has not yet been completed, during this year, many tasks have been accomplished. Most important of all of these tasks, is that, the child is currently using a new assistive walking device.

From the work that has been outlined in this thesis, it can be concluded that the device that the child is currently using at the Nisonger Center Preschool to assist him to walk and interact with his environment is not doing an adequate job. Video analysis shows that the child is walking in crouch gait while in the current assistive walking device. It is not beneficial for him to be walking in this painful manner. Functional analysis of the child's day-to-day activities while in the walker shows that the child benefits from standing even though in his current device he is not standing with proper posture. In addition to this, the child cannot pull up to a desk, a computer or even his peers. From these and other analyses done with the current device used at the Nisonger Center Preschool, it is clear that an improved device is needed in order for the child to benefit from being in an assistive walking device.

The new assistive walking device created for this research project was designed to compensate for the deficiencies of the previous device used for the child. Specific features to be improved on were selected and the design was modeled. It was decided that one of the most important improvements was to have more bodyweight support. The device was also made adjustable so that it could grow with the child. A portable work surface in the form of a tray was also added to the device as a support for the child's arms. It is hoped that these improvements will allow the child to not only walk in a more functional manner, but also stand in a proper posture while in the walking device. A more open front portion of the frame along with a more streamlined frame should allow him to interact with his peers, environment and schoolwork more effectively.

5.2 FUTURE WORK

Over the course of the year, while completing this research project, some aspects of the original project description have not been accomplished. Due to the fact that the device will be built at the end of this quarter, the original goal of validating that the new assistive walker is remains incomplete.

An analysis done by the Occupational Therapy department of the child using the new device would parallel the original analysis that was done for the current device at the Nisonger Center Preschool. The new device is less bulky which should make it easier for the child to interact with his surroundings and peers in addition to being able to pull up to tables and the classroom computer. This functional analysis would show whether or not the new device assists the child in standing in a desired posture with his shoulders aligned over his hips which are in turn aligned over his feet. It would be important that this analysis show that the child's daily functions were improved by using the new device.

Additionally, the data from the initialgait analysis tests, with the child using the walker from the Nisonger Center Preschool, has not been analyzed yet. The original goal for these sets of data was to analyze them and then compare them to data that would have been collected from the gait analysis with the new walker. The data for the new assistive walking device has not been collected. However, if it was collected and analyzed, the comparison of the new and old devices would hopefully validate the effectiveness of the new design with respect to the old. In the interest of time for this research project, it has not been determined whether or not these steps will be accomplished at all.

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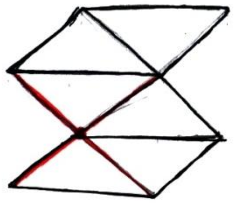
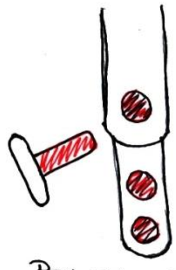
APPENDIX

ADJUSTABILITY

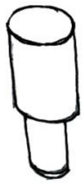


SCISSOR FRAME



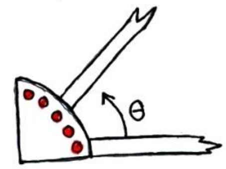
PIN-IN-SLOT

MULTIPLE SCISSORS

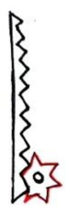


PNEUMATIC CYLINDER

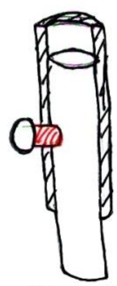
SPRING LOADED



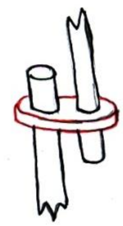
PIVOT ANGLE W/PINS



RACK & PINION



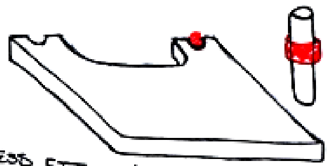
SET SCREW (CURRENT)



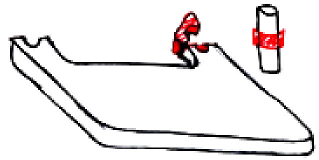
EXTERNAL SHAFTS W/CLAMP

TRIPOD/MUSIC STAND CLAMP

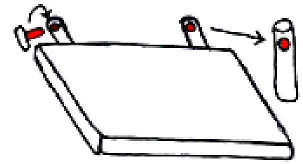
TRAY



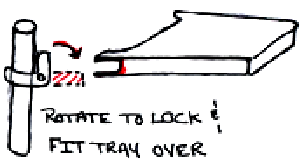
PRESS FIT W/BUSHING ON SHAFT TO KEEP AT SPECIFIED HEIGHT



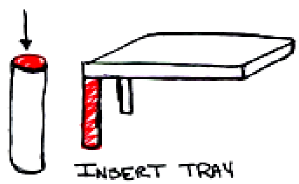
LOCKING HINGE & BUSHING



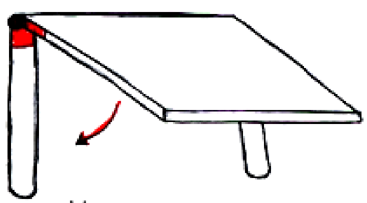
PIN-IN-SLOT



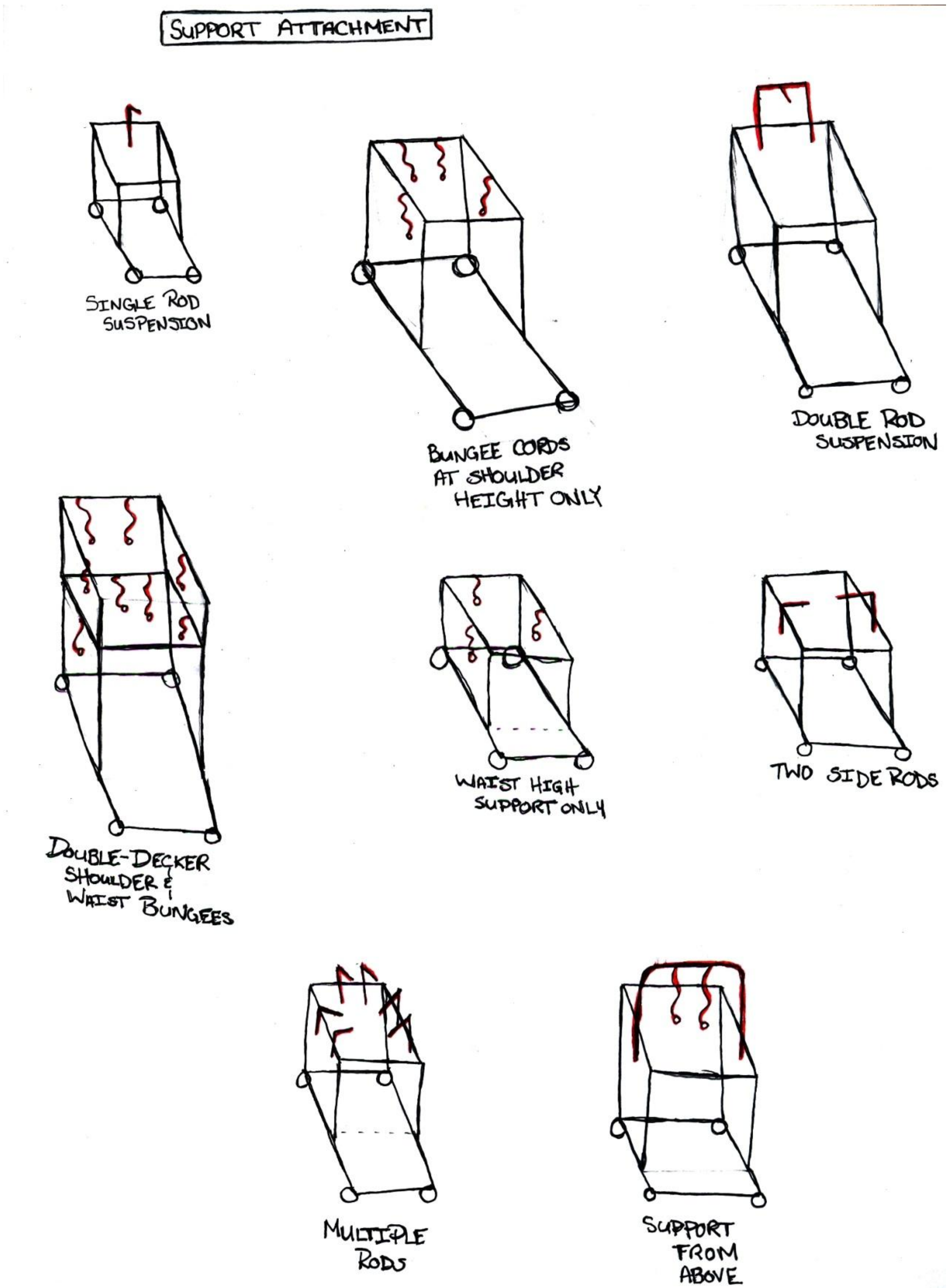
ROTATE TO LOCK & FIT TRAY OVER SHAFT



INSERT TRAY SHAFT INTO FRAME



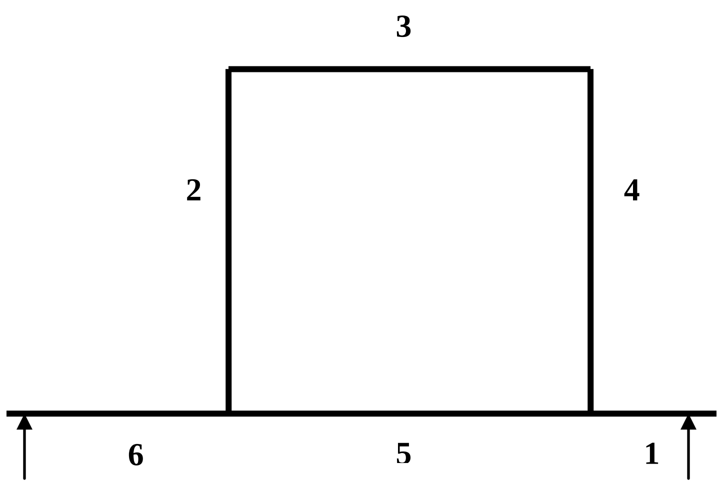
HINGE


SUPPORT ATTACHMENT
SINGLE ROD SUSPENSION
BUNGEE CORDS AT SHOULDER HEIGHT ONLY
DOUBLE ROD SUSPENSION
DOUBLE-DECKER SHOULDER & WAIST BUNGEES
WAIST HIGH SUPPORT ONLY
TWO SIDE RODS
MULTIPLE RODS
SUPPORT FROM ABOVE

Existing Device

Side View COM data:

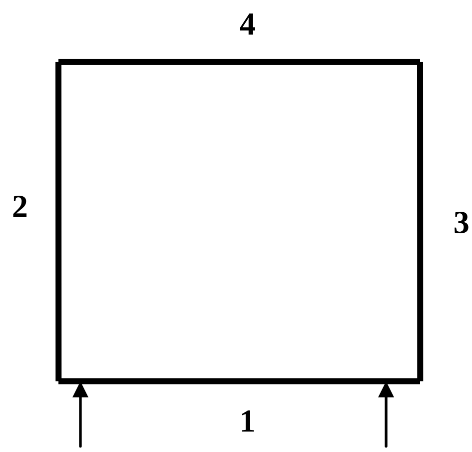
i	COMy (inches)	COMx (inches)	m/ρ
1	**0**	**1.25**	**2.5**
2	**6.5**	**2.5**	**13**
3	**13**	**12.5**	**20**
4	**6.5**	**18**	**13**
5	**0**	**10.25**	**15.5**
6	**0**	**24**	**12**



COMy = 5.65
COMx = 12.72

FrontView COM data:

i	COMy (inches)	COMx (inches)	m/ρ
1	**0**	**9.75**	**19.5**
2	**6.5**	**0**	**13**
3	**13**	**9.75**	**19.5**
4	**6.5**	**13**	**13**

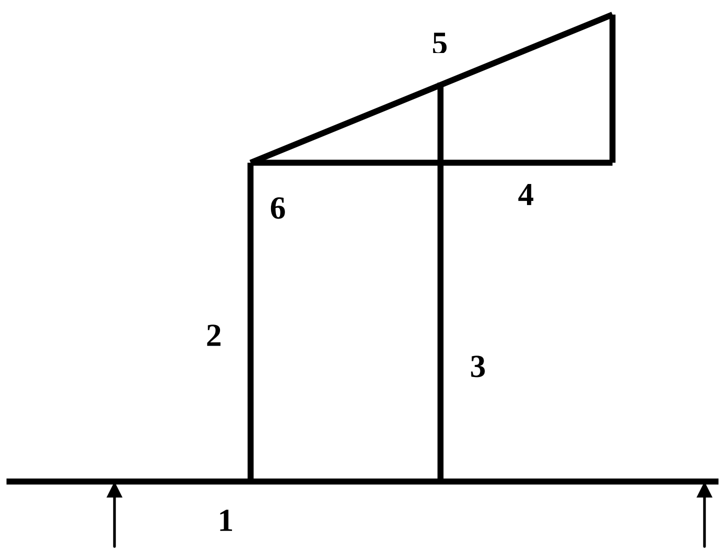


COMy = 6.50
COMx = 9.75

New Device

Side View COM data:

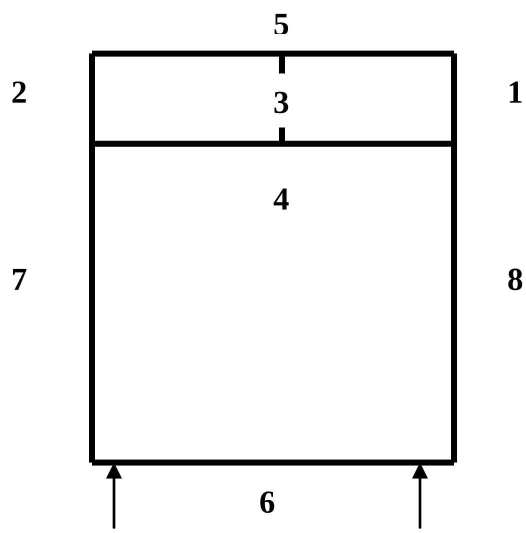
i	COMy (inches)	COMx (inches)	m/ρ
1	**0**	**9**	**24.8**
2	**10.75**	**6**	**16.66**
3	**12.94**	**18**	**20.05**
4	**21.5**	**17**	**17.05**
5	**25.87**	**18**	**16.79**
6	**21.5**	**6**	**4.65**



COMy = 13.4
COMx = 9.43

FrontView COM data:

i	COMy (inches)	COMx (inches)	m/ρ
1	**15.91**	**20**	**31.82**
2	**15.91**	**0**	**31.82**
3	**25.87**	**10**	**4.37**
4	**21.5**	**10**	**20**
5	**31.82**	**10**	**20**
6	**0**	**10**	**20**
7	**10.75**	**0**	**21.5**
8	**10.75**	**20**	**21.5**



COMy = 14.17
COMx = 10.0